

Paleohydrological Changes in Jura (France), and Climatic Oscillations around the North Atlantic from Allerød to Preboreal

Changements paléohydrologiques dans le Jura (France) et oscillations climatiques autour de l'Atlantique Nord de l'Allerød aux débuts de l'Holocène

Paläohydrologische Veränderungen im Jura, Frankreich und klimatische Schwankungen um den Nordatlantik vom Allerød bis zu den Anfängen des Holozän

Michel Magny

Volume 49, numéro 3, 1995

URI : <https://id.erudit.org/iderudit/033062ar>

DOI : <https://doi.org/10.7202/033062ar>

[Aller au sommaire du numéro](#)

Éditeur(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (imprimé)

1492-143X (numérique)

[Découvrir la revue](#)

Citer cet article

Magny, M. (1995). Paleohydrological Changes in Jura (France), and Climatic Oscillations around the North Atlantic from Allerød to Preboreal. *Géographie physique et Quaternaire*, 49(3), 401–408. <https://doi.org/10.7202/033062ar>

Résumé de l'article

Les changements paléohydrologiques enregistrés dans les remplissages des lacs du Jura permettent de proposer une reconstitution détaillée des oscillations climatiques de l'Allerød aux débuts de l'Holocène. Trois phases sont distinguées à l'intérieur du Dryas récent : une phase à bilan hydrique déficitaire encadrée par deux phases humides. D'autre part, deux courtes phases de hausse du niveau des lacs surviennent avant et après le Dryas récent, interrompant momentanément la baisse des plans d'eau qui se développe pendant l'Allerød et le Préboréal. Ces oscillations climatiques reconstituées dans le Jura apparaissent en phase avec les mouvements des glaciers et de la limite supérieure de la forêt dans les Alpes, avec les stratigraphies isotopiques établies dans les lacs suisses et au Groenland ainsi qu'avec des oscillations climatiques enregistrées en mer de Norvège. D'autres corrélations entre ces oscillations climatiques, les plateaux du radiocarbone repérés dans les lacs suisses et les fluctuations du résiduel $\Delta^{14}\text{C}$ résiduel indiquent l'existence d'une corrélation entre les changements paléohydrologiques reconnus dans le Jura et des oscillations plus globales du climat. Elles renforcent aussi l'idée d'un lien entre la circulation océanique et les changements climatiques affectant alors l'Europe occidentale et centrale. Enfin, elles permettent de proposer des références chronologiques de haute précision pour les changements climatiques et environnementaux survenant au début de l'Holocène.

PALEOHYDROLOGICAL CHANGES IN JURA (FRANCE), AND CLIMATIC OSCILLATIONS AROUND THE NORTH ATLANTIC FROM ALLERØD TO PREBOREAL

Michel MAGNY, Laboratoire de Chrono-écologie, UMR 9946 du CNRS, UFR des Sciences et Techniques, 16, route de Gray, 25030 Besançon, France.

ABSTRACT Regional palaeohydrological changes recorded in the Jura lakes, France, have led to a tentative reconstruction of a fine-scale pattern of climatic changes from Allerød to the early Holocene. The Younger Dryas (YD) can be subdivided into three parts: after a first wet phase, this cool period was characterized by increasing dryness; a short rise in lake level developed during its last part. Moreover, the YD was preceded and followed by two short rises in lake-level, which interrupted the lake-level lowerings developing during the Allerød and the Preboreal. Climatic oscillations reconstructed in Jura appear to be in phase with glacier and tree-limit movements in the Alps, with fluctuations in oxygen-isotope records from the Swiss lakes and the Greenland ice sheet, and with climatic oscillations recorded in the Norwegian Sea. Other correlations between (1) these climatic oscillations, (2) ^{14}C plateaux recorded in Swiss lake sequences, and (3) fluctuations in the residual $\Delta^{14}\text{C}$, support a correlation between regional palaeohydrological changes defined in Jura and broad-scale climatic oscillations; they also support the existence of a link between climatic changes in Western and Central Europe and oceanic circulation. Moreover, as working hypothesis, these correlations suggest high-precision timing for the climatic and environmental changes occurring during the early Holocene.

RÉSUMÉ *Changements paléohydrologiques dans le Jura (France) et oscillations climatiques autour de l'Atlantique Nord de l'Allerød aux débuts de l'Holocène.* Les changements paléohydrologiques enregistrés dans les remplissages des lacs du Jura permettent de proposer une reconstitution détaillée des oscillations climatiques de l'Allerød aux débuts de l'Holocène. Trois phases sont distinguées à l'intérieur du Dryas récent : une phase à bilan hydrique déficitaire encadrée par deux phases humides. D'autre part, deux courtes phases de hausse du niveau des lacs surviennent avant et après le Dryas récent, interrompant momentanément la baisse des plans d'eau qui se développe pendant l'Allerød et le Préboréal. Ces oscillations climatiques reconstituées dans le Jura apparaissent en phase avec les mouvements des glaciers et de la limite supérieure de la forêt dans les Alpes, avec les stratigraphies isotopiques établies dans les lacs suisses et au Groenland ainsi qu'avec des oscillations climatiques enregistrées en mer de Norvège. D'autres corrélations entre ces oscillations climatiques, les plateaux du radiocarbone repérés dans les lacs suisses et les fluctuations du $\Delta^{14}\text{C}$ résiduel indiquent l'existence d'une corrélation entre les changements paléohydrologiques reconnus dans le Jura et des oscillations plus globales du climat. Elles renforcent aussi l'idée d'un lien entre la circulation océanique et les changements climatiques affectant alors l'Europe occidentale et centrale. Enfin, elles permettent de proposer des références chronologiques de haute précision pour les changements climatiques et environnementaux survenant au début de l'Holocène.

ZUSAMMENFASSUNG *Paläohydrologische Veränderungen im Jura, Frankreich und klimatische Schwankungen um den Nordatlantik vom Allerød bis zu den Anfängen des Holozän.* In den Juraseen festgestellte regionale paläohydrologische Veränderungen erlaubten eine vorläufige detaillierte Rekonstruktion der klimatischen Wechsel vom Allerød bis zum frühen Holozän. Die jüngere Dryaszeit kann in drei Phasen unterteilt werden: nach einer ersten feuchten Phase, charakterisierte sich die darauffolgende kalte Periode durch zunehmende Trockenheit; während der letzten Phase entwickelte sich eine kurze Anhebung des Seenniveaus. Außerdem gab es zwei kurze Anhebungen des Seenniveaus, eine vor und eine nach der Dryaszeit, welche die Senkungen des Seenniveaus, die während des Allerød und dem frühen Holozän auftraten, unterbrachen. Die im Jura rekonstruierten klimatischen Schwankungen scheinen mit den Gletscher- und Baumgrenze-Bewegungen in den Alpen zeitlich übereinzustimmen, wie auch mit den Fluktuationen in den Sauerstoffisotopenbelegen von Schweizer Seen und der Grönland-Eisdecke, und mit den im norwegischen Meer festgestellten Klimaschwankungen. Andere Korrelationen zwischen (1) diesen Klimaschwankungen, (2) ^{14}C Plateaux, die in Schweizer Seen-Sequenzen festgestellt wurden und (3) Fluktuationen im $\Delta^{14}\text{C}$ Rückstand, stützen eine Korrelation zwischen den im Jura festgestellten regionalen paläohydrologischen Veränderungen und globaleren Klimaschwankungen; sie stützen auch die Annahme einer Beziehung zwischen den Klimawechseln in West- und Zentraleuropa und der Ozeanströmung.

INTRODUCTION

Recent warming enhances an urgent need to understand the dynamics of climatic changes. The study of past climates can contribute to this understanding by offering references for natural factors controlling climatic oscillations. The abrupt cooling characterizing the Younger Dryas and the subsequent warming occurring during the early Holocene certainly constitute the most prominent broad-scale climatic events of the last 12 000 years. Thus, their study is of particular interest.

Investigations carried out in the Jura lakes, France, have recently provided high-resolution records of the time span *ca.* 11 500-9000 BP (Magny and Ruffaldi, 1995). This paper has three aims:

- (1) To present a fine-scale pattern of palaeohydrological changes during the Younger Dryas and the early Holocene from the Jura lakes.
- (2) To attempt correlations between this regional palaeohydrological pattern and records of more global significance, by comparing the Jurassien proxy data with data obtained from continental, ice sheet and oceanic records around the North Atlantic area.
- (3) To discuss several implications of these tentative correlations, in particular with regard to the link between palaeohydrological oscillations on the European continent and changes in ocean circulation during the deglaciation.

Below, dating of palaeoclimatic events is indicated by uncalibrated radiocarbon dates: BP, and calibrated radiocarbon dates: cal. BP. Dates obtained from yearly laminated Greenland ice cores are expressed in cryo-years.

PALAEOHYDROLOGICAL CHANGES IN JURA FROM *ca.* 11 500 to *ca.* 9000 BP

The Jura range is a medium sized mountain chain culminating at 1723 m. Sedimentological and palynological analyses of stratigraphical sequences from three lakes of central Jura (Fig. 1): Onoz (560 m), Remoray (851 m) and Saint-Point (850 m) led to the reconstruction of a detailed pattern of lake-level fluctuations from the late Allerød to the early Holocene. The lake-level changes are reconstructed on the basis of the use of multiple lines of evidence, *i.e.* changes in (1) the sediment texture, (2) the sediment composition (lithology), and (3) the frequency and the types of carbonate concretions in lake marl. Hiatus evidenced by pollen stratigraphy also can give further indications (Magny, 1992a, b). Figure 2 presents the records of lake-level changes obtained at lakes Onoz, Remoray and Saint-Point (Magny and Ruffaldi, 1995). The chronology is based on a layer of Laacher See tephra (Bogaard and Schmincke, 1985) and on pollen zones; today, the lateglacial and Holocene vegetation history in the Jura mountains is well known and has benefitted from numerous radiocarbon datings (Wegmüller, 1966; Richard, 1983; Ruffaldi, 1993; de Beaulieu *et al.*, 1994) (Table I). Several rises in lake level can be distinguished as follows:

- The Allerød period corresponds to a lowering phase interrupted by a rise in lake level (the transgressive Onoz 1 phase) developing just before the Laacher See tephra deposition, *i.e.* around 11 000 BP.
- The start of the Younger Dryas (YDS) coincides with an abrupt rise in lake level (the transgressive Onoz 2 phase). Then, this period is marked by a progressive fall in the water level. This drying could correspond to the culmination of the climatic deterioration. A short transgressive phase (Onoz 3 phase) developed just before the Younger Dryas termination (YDT). By referring to a YD duration of *ca.* 1300 calendar years (Stuiver and Braziunas, 1993), the sedimentation rate shown by the stratigraphical sequence of Lake Onoz suggests that the rise in lake level corresponding to the Allerød-YD transition (*i.e.* the beginning of the Onoz 2 phase) took less than 50 years. In the same way, the Onoz 3 phase marking the last part of YD has a duration shorter than 200 years.
- The transition from the YD to the Preboreal is characterized by a fall in water level. This low lake level characterized most of the Preboreal. It was interrupted only by a short but well-recorded transgressive phase, *i.e.* the Remoray phase. By referring to a YDT dated at 11 650±250 cryo-years BP (Stuiver and Braziunas, 1993) and a Preboreal-Boreal transition dated at *ca.* 9950 cal. BP in Jura, the sedimentation rate shown by the stratigraphical sequence of Lake Remoray would suggest that this phase of rising lake level developed between *ca.* 11 110 and 10 730 cal. BP.

The lowering of lake level in Jura during the Preboreal has also been observed at two other sites: (1) In southern Jura, Richard (1991) reconstructed a similar regressive phase from the stratigraphical sequence of Lake Bart. Here, a peat layer interbedded between two lake-marl layers and dated at 9630±360 BP indicates a major lowering phase (overgrowing); moreover, this low water level is underlined

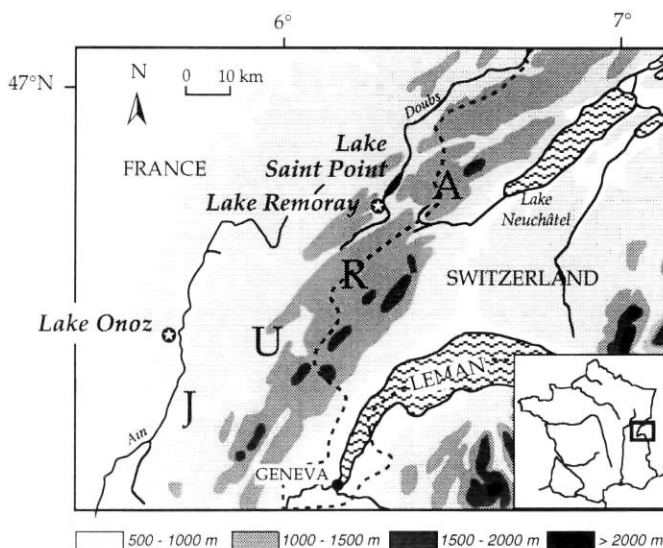


FIGURE 1. Location of the investigation area and studied sites.
Région d'étude et localisation des sites de référence.

by a hiatus in the pollen assemblages. (2) In northern Jura, in the stratigraphical sequence of Lake Chaillexon, the Preboreal also corresponds to a hiatus in sedimentation; this would suggest a major water-level lowering reaching 9 m (Di Giovanni, 1994).

- The transgressive Joux phase developing during the Boreal could have begun as early as the late Preboreal at Remoray (*i.e.* ca. 10 250 cal. BP from the sedimentation rate). It ended at ca. 8950 cal. BP.

The palaeohydrological pattern reconstructed from lacustrine sequences of Jura for the YD and the early Holocene is in good agreement with that established in the Alps and in other European countries for the same periods. From pollen data in Upper Valais (Switzerland), Markgraf (1969) distinguished two main phases in the YD: an older one believed to be rather oceanic and a younger one thought to be more continental. Kerschner (1980) outlined a similar climatic pattern from glaciers in the Alps during the Egesen phase (*i.e.* YD). This deficit in water balance developing during the YD cold period has also been evidenced by Guiot and Pons (1986) and Pons *et al.* (1987); using a quantitative reconstruction method from pollen time-series, they highlight a marked cooling accompanied by a large decrease in precipitation in France and eastern Spain. Hence, by referring to this palaeohydrological scheme, the increased values of *Filipendula* and *Betula* discussed by Lotter *et al.* (1992) in Swiss lakes during the PAZ CHb-4b2 should be attributed not to a wetter climate, but to a lowering of lake levels and to development of wider moist zones around these lakes.

Thus, three phases can be distinguished during the YD. The first is characterized by an abrupt cooling and by a wet climate; this is termed the Onoz 2 phase. The second is

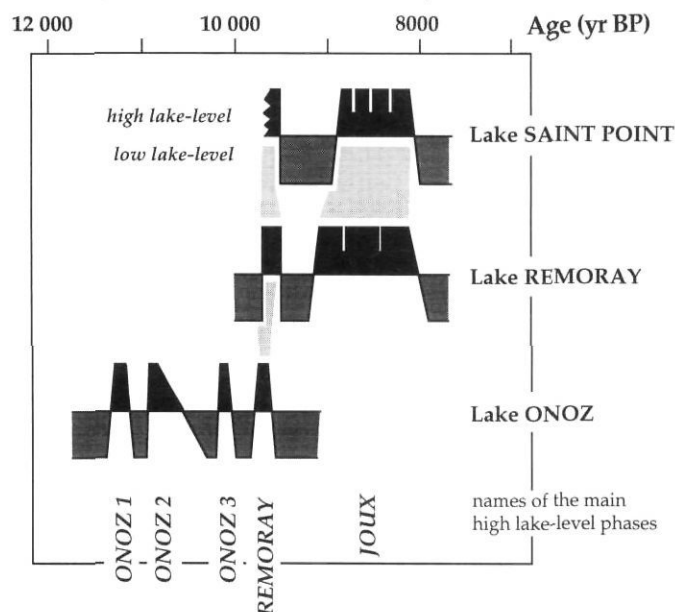


FIGURE 2. Palaeohydrological changes recorded in the lakes Onoz, Remoray and Saint-Point between 11 500 and 8000 BP.

Changements paléohydrologiques enregistrés dans les lacs d'Onoz, de Remoray et de Saint-Point entre 11 500 et 8000 BP.

marked by a progressive drying; it could correspond to the culmination of the climatic deterioration. These first and second phases could be correlated with the two phases distinguished by Markgraf (1969) and Kerschner (1980) in the Alps. An additional third phase, evidenced from the high-resolution record of Lake Onoz and termed the Onoz 3 phase, shows increasing wetness at the YDT and could indicate a rapid inversion of the climatic trend preceding the marked climatic warming at the YD-Preboreal transition. All these Jurassien lacustrine sequences indicate that the Preboreal considered as a whole coincides with a fall of lake level, giving evidence of a significant deficit in water budget. Ammann (1989), Gaillard (1984) and Digerfeldt (1988) arrive at a similar palaeohydrological pattern in Switzerland and South Sweden. Starkel (1991) also highlights a reduction in the water discharge of the Upper Vistula in Poland during this period. The data synthesized by Gaillard (1985) support the idea that this lowering phase is a widespread European phenomenon.

In Jura, as already mentioned, this Preboreal phase of negative water budget appears to be interrupted by a short phase of positive water balance, termed the Remoray phase. From a pollen/mollusc/ostracod sequence in South Wales (UK), Walker *et al.* (1993) reconstructed similar warm and dry conditions for the Preboreal and identified a short-lived climatic cooling in the middle of the tenth millennium BP. In Scania, records from lakes Torreberga (Digerfeldt, 1971) and Krageholmssjön (Gaillard, 1984) also show a phase of increased lake level occurring between 10 000 and 9500 BP.

The lake level lowering observed in Jura during the Preboreal is synchronous with a general retreat of glacier tongues in the Austrian and Swiss Alps (Patzelt, 1977; Zoller, 1977). It marks the climatic warming developing after the YD. Moreover, the short-lived climatic oscillation, termed the Remoray phase in Jura, can be correlated in the Alps with a similar cold event marked by a glacier advance (Patzelt, 1977; Zoller, 1977) and a tree-limit decline, termed the Palü phase by Burga (1988). In the same way, the

TABLE I
Correlation of the Jura pollen-zone system to ^{14}C chronology (conventional and calibrated).

Pollen zone	Age (yr BP)	Age (cal. yr BP)
	8 000	8 850
Boreal		
	9 000	9 980
Preboreal		
	10 000	11 150
Younger Dryas		
	11 000	12 920
Allerød		
	12 000	13 990

From De Beaulieu *et al.* (1994).

Italics indicate calibrated dates by comparison of the U-Th and ^{14}C ages of the Barbados corals.

transgressive Joux phase coincides with a glacier advance and a tree-limit decline in the Alps, termed the Venediger-Schams phase (Patzelt, 1977; Zoller, 1977) (Fig. 5).

CLIMATIC OSCILLATIONS, OXYGEN-ISOTOPE STRATIGRAPHY AND RESIDUAL $\Delta^{14}\text{C}$ RECORD

The palaeoclimatic pattern previously reconstructed from Jura lakes and Alpine sites matches with that evidenced by Lotter *et al.* (1992) for the Swiss lakes and with the correlations they make with the Greenland ice sheet (Fig. 3). The oxygen-isotope stratigraphies obtained in Swiss Plateau and in Greenland highlights that the Younger Dryas is preceded and followed by two distinct short climatic oscillations, respectively termed the Gerzensee and the P fluctuation (*i.e.* Preboreal fluctuation). Thus, the Onoz 1 phase appears to be synchronous with the Gerzensee fluctuation also occurring shortly before the deposition of the Laacher See tephra; the Remoray phase (Fig. 2) can be correlated with the P oscillation (Fig. 4).

The palaeoclimatic pattern established from Jura, the Swiss Plateau and the Alps can be also correlated with the curve of the residual $\Delta^{14}\text{C}$ recently extended back to 11 400 cal. BP (Stuiver *et al.*, 1993) from tree-ring series. Figure 5 shows tentative correlations between (1) the residual $\Delta^{14}\text{C}$ curve as published by Stuiver and Reimer (1993) and (2) the Jurassic and Alpine glacier records (Magny, 1995). The palaeoclimatic events were dated in solar years by calibration of their radiocarbon chronology from Stuiver and Reimer (1993). Despite the uncertainty inherent in the radiocarbon method (standard deviation), the Jurassic lakes, the Alpine glaciers and the $\Delta^{14}\text{C}$ record display fluctuations showing a similar *rhythm*: the rises in lake level in Jura and the glacier advances in the Alps appear to be synchronous with $\Delta^{14}\text{C}$ maxima, and inversely. Stuiver and Braziunas (1993) suggested that during the early Holocene, the $\Delta^{14}\text{C}$ oscillations reflect an oceanic forcing. $\Delta^{14}\text{C}$ maxima should be linked to changes in thermohaline circulation: a reduced upwelling of ^{14}C -deficient water increases surface ocean and atmospheric $\Delta^{14}\text{C}$ levels. Thus, the phases characterized by low lake level in Jura, glacier retreat and rise in tree limit in Alps would be associated with a strengthened North Atlantic Deep Water (NADW) flow, and the phases marked by rises in lake level in Jura, glacier advance and tree-limit fall in the Alps would be associated with a smaller NADW flow. From the $\Delta^{14}\text{C}$ residual curve, the YD-Holocene transition and the climatic improvement following the Palü/Remoray phase does coincide with two noticeable drops in $\Delta^{14}\text{C}$ values inducing ^{14}C plateaus in palaeoenvironmental records. From a detailed lateglacial and early Holocene radiocarbon stratigraphy established by Ammann and Lotter (1988) and Zbinden *et al.* (1989) for the Swiss Plateau, three ^{14}C plateaus have been highlighted at ca. 12 700, 10 000 and 9500 BP. The first and the second coincide respectively with the Oldest Dryas-Bølling transition and the YD-Holocene transition. The third appears to be synchronous with the P oscillation. The correlations between palaeoclimatic data and $\Delta^{14}\text{C}$ falls appear to be in agreement with the ^{14}C plateaus defined for the same periods in Switzerland.

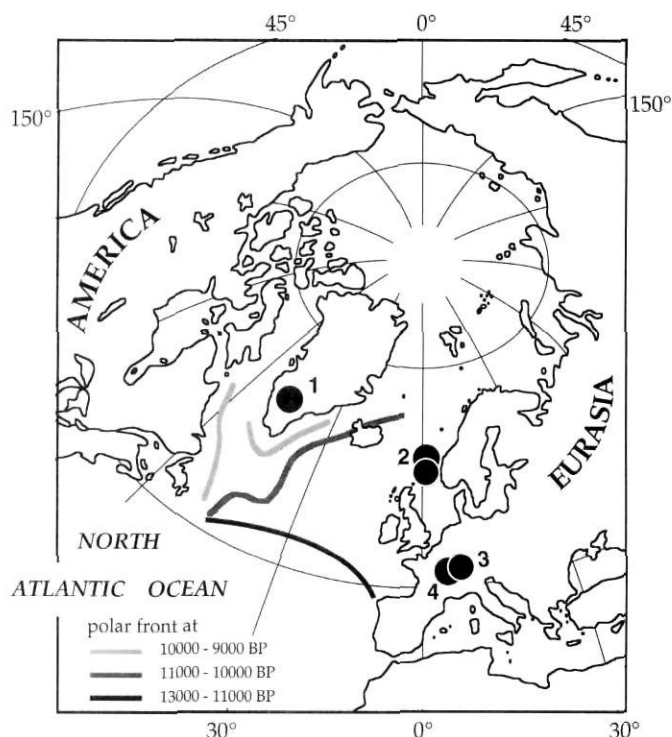


FIGURE 3. Reference sites around the North Atlantic: (1) Dye 3, Greenland (from Dansgaard *et al.*, 1989); (2) Cores HM 79 6/4 (from Karpuz and Jansen, 1992) and Troll 3.1 (from Lehman and Keigwin, 1992); (3) Swiss Plateau and Alps; (4) Jurassic lakes. The successive positions of the polar front are drawn from Ruddiman and McIntyre (1981).

Position des sites de référence autour de l'Atlantique Nord : (1) Dye 3, Groenland (d'après Dansgaard *et al.*, 1989); (2) Sondages HM 79 6/4 (d'après Karpuz et Jansen, 1992) et Troll 3.1 (d'après Lehman et Keigwin, 1992); (3) Plateau et Alpes suisses; (4) lacs jurassiens. Les positions successives du front polaire sont indiquées d'après Ruddiman et McIntyre (1981).

PALAEOCLIMATIC RECORDS FROM THE NORWEGIAN SEA

The correlations just proposed between palaeoclimatic records in Jura, the Swiss Plateau and the Alps and changes in oceanic circulation by referring to the residual $\Delta^{14}\text{C}$ curve appear to be supported by the results obtained by Lehman and Keigwin (1992) from the Norwegian Sea (Fig. 6). Faunal analyses of oceanic cores led these authors to distinguish in particular an Intra Allerød Cold Period (IACP) and a Preboreal oscillation (PB) respectively preceding and following the Younger Dryas. They correlated these climatic oscillations with those defined from oxygen-isotope stratigraphy in the Swiss lakes and interpreted them as sudden changes in thermohaline circulation.

The diatom record established by Karpuz and Jansen (1992) from two other cores from the Norwegian Sea presents strong similarities with that of Lehman and Keigwin. They distinguish a brief cooler condition occurring between 9900 and 9600 BP, termed the second YD; moreover, despite some chronological discrepancies, the Younger Dryas also appears here to be preceded by several short-lived

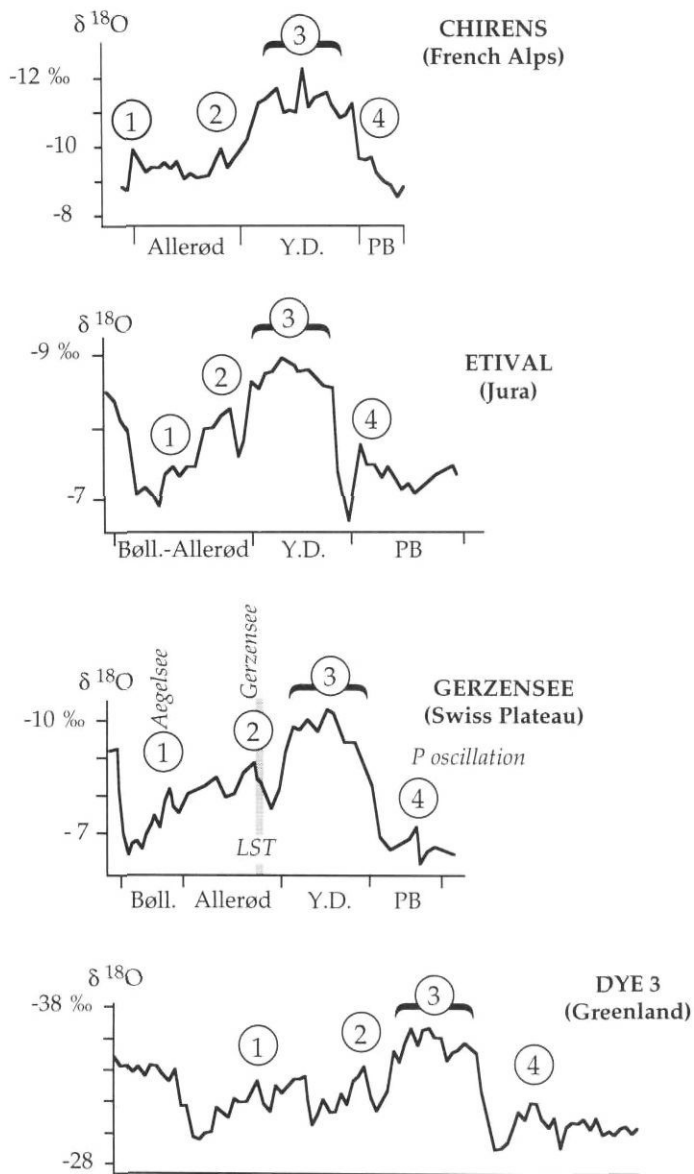


FIGURE 4. Tentative correlations between oxygen-isotope stratigraphies of sites from the French Alps (Chirens, from Eicher, 1987), Jura (Etival, from Campy *et al.*, 1983), Swiss Plateau (Gerzensee, from Lotter *et al.*, 1992) and Greenland (Dye 3, from Lotter *et al.*, 1992). LST: Laacher See Tephra. Oscillation 3 corresponds to the Younger Dryas. The abscissa axis corresponds to a depth scale; pollen analysis provides additional chronological references at lakes Chirens, Etival and Gerzensee.

*Essai de corrélation entre les stratigraphies isotopiques de sites des Alpes françaises (Chirens, d'après Eicher, 1987), du Jura (Étival, d'après Campy *et al.*, 1983), du Plateau suisse (Gerzensee, d'après Lotter *et al.*, 1992) et du Groenland (Dye 3, d'après Lotter *et al.*, 1992). LST: Laacher See Tephra. L'oscillation 3 correspond au Dryas récent. L'axe des abscisses correspond à une échelle de profondeur. Dans le cas des sites de Chirens, Etival et Gerzensee, l'analyse pollinique livre des références chronologiques complémentaires.*

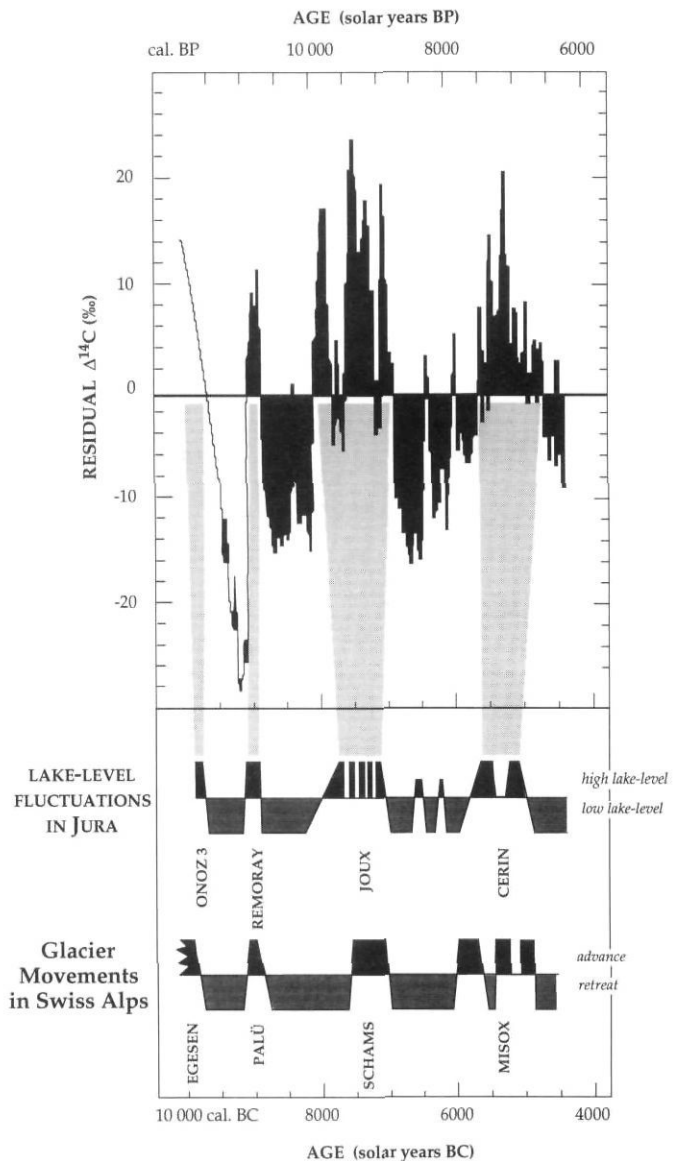


FIGURE 5. Tentative correlations between the curve of the residual $\Delta^{14}\text{C}$ (from Stuiver and Braziunas, 1993), the level fluctuations of the Jura lakes (from Magny, 1995) and the movements of the glacier and timberline in the Swiss Alps (from Zoller, 1977 and Burga, 1988).

Essai de corrélation entre la courbe du $\Delta^{14}\text{C}$ résiduel (d'après Stuiver et Braziunas, 1993), les fluctuations du niveau des lacs jurassiens (d'après Magny, 1995) et les mouvements des glaciers et de la limite supérieure de la forêt dans les Alpes suisses (d'après Zoller, 1977 et Burga, 1988).

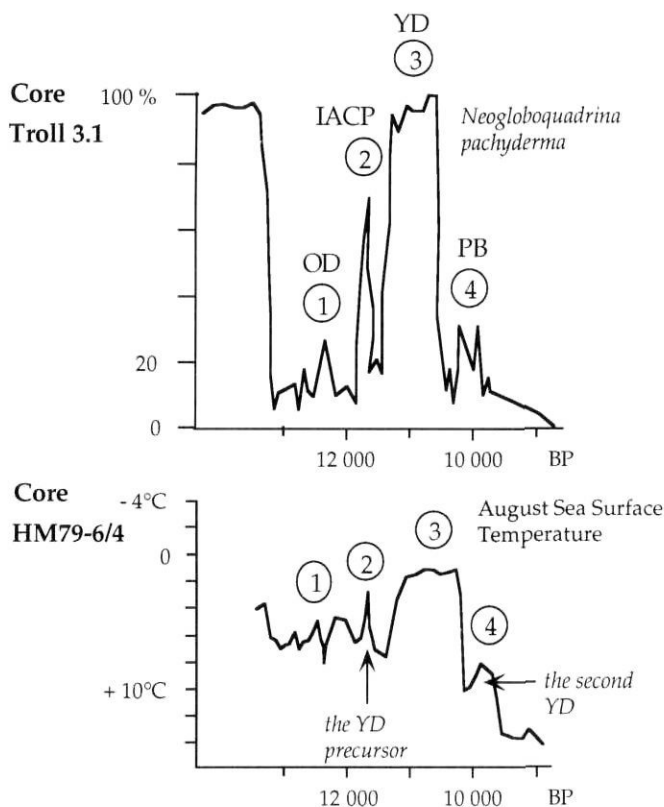


FIGURE 6. Tentative correlations between environmental changes recorded in oceanic cores from the Norwegian Sea (Lehman and Keigwin, 1992; Karpuz and Jansen, 1992). Oscillation 3 corresponds to the Younger Dryas.

Essai de corrélation entre les changements environnementaux reconstitués à partir de sondages océaniques en mer de Norvège (Lehman et Keigwin, 1992; Karpuz et Jansen, 1992). L'oscillation 3 correspond au Dryas récent.

climatic oscillations, which could be correlated with the OD (*i.e.* Older Dryas) and IACP (*i.e.* Intra-Allerød Cold Period) fluctuations defined by Lehman and Keigwin, with the Aegelsee and Gerzensee fluctuations defined by Lotter *et al.* (1992) in the Swiss plateau, or with the Onoz 1 phase defined in Jura during the Bølling-Allerød interstade.

DISCUSSION

The proxy data presented here from continental, ice sheet and oceanic sites around the North Atlantic suggest to recognize the existence of a similar *rhythm* in climatic oscillations between *ca.* 12 000 and 9000 BP and to propose a consistent fine-scale pattern of climatic changes for this time span. The Younger Dryas major cold event appears to be preceded and followed by minor short-lived oscillations well recorded in high-resolution stratigraphical sequences in different types of environment. Thus, the Killarney oscillation recognized from multiple lines of evidence in Eastern Canada (Cwynar *et al.* 1994), appears to be an equivalent to the Onoz phase 1, also termed Gerzensee phase in the Swiss Plateau and IACP in the Norwegian Sea. The magnitude of the cold events increases before and decreases

after the Younger Dryas. Oxygen-isotope records display most often stepwise decreasing temperature via several climatic oscillations during the Bølling-Allerød interstade, and a more rapid warming at the YD-Holocene transition.

Direct correlations between continental and oceanic sequences support the idea of a link between (1) thermal and palaeohydrological oscillations on the European continent and Northern high latitudes, and (2) changes in oceanic circulation (Lehman and Keigwin, 1992). This link is also supported by the correlations observed between (1) palaeoclimatic records from Jura lakes and Alpine glaciers and (2) the residual $\Delta^{14}\text{C}$ record. Direct stratigraphical correlations observed between ^{14}C plateaus and palaeo-environmental changes in Swiss sequences corroborate this pattern.

No tree-ring record is available to extend the residual $\Delta^{14}\text{C}$ curve beyond 11 400 cal. BP. The ^{14}C curve reconstructed from Swiss lake records by Zbinden *et al.* (1989) and the proxy data from continental and oceanic records tentatively suggest similar correlations between changes in residual $\Delta^{14}\text{C}$, oceanic circulation and climate during the Bølling-Allerød interstade. From Zbinden *et al.* (1989), the climatic warming at the oldest Dryas-Bølling transition is well marked by a ^{14}C plateau, and then the stepwise cooling developing during the interstade is synchronous with an increase in the $\Delta^{14}\text{C}$ values. It can be speculated that the Aegelsee and the Onoz 1-Gerzensee oscillations could correspond to (minor?) peaks of $\Delta^{14}\text{C}$ and that the abrupt YDS could coincide with a similar strong rise in residual $\Delta^{14}\text{C}$.

The palaeoclimatic records from the Jura lakes show that *broad-scale* climatic fluctuations can induce different types of palaeohydrological changes on a *regional scale*. Minor and short-lived climatic coolings coincide with rises in lake level. The Younger Dryas major cold event shows a more complex picture: the YDS and the YDT correspond to transgressive phases, but the culmination of the cooling occurred during a well-marked drying. Ruddiman and McIntyre (1981) associated the YD with a readvance of the North Atlantic polar front (Fig. 3); this readvance reached its most southward position between 11 000 and 10 000 BP. This southward position could have induced the water deficit evidenced in Jura between the Onoz 2 and 3 phases, due to a combination of several factors such as (1) a development of a continental high-pressure cell in Eurasia, (2) more frequent incursions of dry and cold polar air into Western Europe, and (3) a weaker evaporation on the cold North Atlantic. The Onoz 1-2-3 and Remoray phases could be associated with less southward readvances of the polar front explaining a positive water budget in Western and Central Europe. The deficit in water budget developing during the early Holocene between *ca.* 10 000 and 9000 BP and inducing a low lake level in Jura and glacier retreat in the Alps marks the climatic improvement following the YDT. It also reflects the summer-insolation maximum characterizing the early Holocene (Berger, 1979; Harrison, 1988) and effects of residual ice sheets on the atmospheric circulation (COHMAP, 1988; Harrison *et al.*, 1992).

The fine-scale palaeoclimatic pattern outlined suggests that the early Holocene was still marked by abrupt climatic changes synchronous with changes in the oceanic circulation (Bard *et al.*, 1987; Mörner, 1993; NASP Members, 1994). By referring to the residual $\Delta^{14}\text{C}$ curve, the climatic oscillation termed the second YD, PB or P oscillation, Remoray or Palü phase, could be precisely dated between 10 950 and 10 750 cal. BP. Moreover, by reference to (1) stratigraphical correlations between palaeoenvironmental changes and ^{14}C plateaus and (2) the residual $\Delta^{14}\text{C}$ curve, the YD-Holocene transition can be situated at ca. 11 650 cal. BP in agreement with the observations of Stuiver and Braziunas (1993). Karpuz and Jansen (1992) proposed that the increased meltwater flux at meltwater pulse IB (Fairbanks, 1989) might have been the cause of the "second YD". This pattern appears to be consistent with the large drop of residual $\Delta^{14}\text{C}$ before 11 150 cal. BP. But, as discussed by Stuiver and Braziunas (1993), some uncertainties still persist concerning the precise chronological position of the meltwater pulse IB.

Difficulties with the fine-scale reconstructions arise from the lack of absolute chronological references. The standard deviation in the radiocarbon datings leads to insufficient time accuracy in comparison with the need to correlate short-term events reported by continental and oceanic records. Ash layers can offer further high-precision but only relative references. In this context, correlations can be attempted by reference to *rhythm* and *magnitude* reconstructed in sequences of environmental changes and to *coherence* of the patterns reconstructed by assemblage of different types of palaeoclimatic records. Despite these difficulties, tentative fine-scale reconstructions of past climatic changes need further development to assess at what time scale natural factors interact in climate dynamics. Moreover, the previous discussion would suggest interesting hypothesis for dating palaeoenvironmental changes during the early Holocene in calendar years by correlations with the fluctuations of the residual $\Delta^{14}\text{C}$.

ACKNOWLEDGMENTS

These investigations have been supported by the CNRS and the Ministère de la Recherche et de la Technologie (France). The author express its sincere thanks to Dr Marilyn Gill (Besançon) for her help with English translation of the manuscript, and to Jean-Claude Rougeot (Besançon) for his help with the figure drawing. The author is also grateful to Jacques-Louis de Beaulieu and an anonymous reviewer for their very useful comments.

REFERENCES

- Ammann, B., 1989. Late-Quaternary palynology at Lobsigensee. Regional vegetation history and local lake development. *Dissertationes Botanicae*, 137: 1-157.
- Ammann, B. and Lotter, A., 1989. Late-Glacial radiocarbon- and palynostratigraphy on the Swiss Plateau. *Boreas*, 18: 109-126.
- Bard, E., Arnold, M., Maurice, P., Duprat, J., Moyes, J. and Duplessy, J.C., 1987. Retreat velocity of the North Atlantic polar front during the last deglaciation determined by ^{14}C accelerator mass spectrometry. *Nature*, 328: 791-794.
- Berger, A., 1979. Insolation signatures of Quaternary climatic changes. II *Nuovo Cimento*, 2: 63-87.
- Bogaard, P.V.D. and Schmincke, H.U., 1985. Laacher See Tephra: A widespread isochronous late Quaternary tephra layer in central and northern Europe. *Geological Society of America Bulletin*, 96: 1554-1571.
- Burga, C., 1988. Swiss vegetation history during the last 18 000 years. *New Phytologist*, 110: 581-602.
- Campy, M., Chaix, L., Eicher, U., Mouthon, J., Richard, H. and Urlacher, J.P., 1983. L'Aurochs (*Bos primigenius* Boj.) d'Étival (Jura, France) et la séquence tardi- et postglaciaire sur les plateaux jurassiens. *Revue de Paléobiologie*, 2-1: 61-85.
- COHMAP Members, 1988. Climatic changes of the last 18000 years: Observations and models simulations. *Science*, 241: 1043-1052.
- Cwynar, L. C., Levesque, A. J., Mayle, F. E. and Walker, I., 1994. Wisconsin Late-Glacial environmental change in New Brunswick: A regional synthesis. *Journal of Quaternary Science*, 9: 161-164.
- Dansgaard, W., White, J.W.C. and Johnson, S.J., 1989. The abrupt termination of the Younger Dryas climate event. *Nature*, 339: 532-534.
- De Beaulieu, J. L., Richard, H., Ruffaldi, P. and Clerc, J., 1994. History of vegetation, climate and human action in the French Alps and the Jura over the last 15 000 years. *Dissertationes Botanicae*, 234: 253-275.
- Digerfeldt, G., 1971. The Post-glacial development of the ancient lake of Torneberg, Scania, South Sweden. *Geologiska Föreningens i Stockholm Föreläsningar*, 93: 601-624.
- Digerfeldt, G., 1988. Reconstruction and regional correlation of Holocene lake-level fluctuations in lake Bysjön, South Sweden. *Boreas*, 17: 165-182.
- Di Giovanni, C., 1994. Production, flux et stocks de matière organique dans un système limnologique au cours du Post-glaciaire. Le bassin de Chaillexon (Doubs, France). Thesis, Université de Bourgogne, 290 p.
- Eicher, U., 1987. Die spätglazialen sowie frühpostglazialen Klimaverhältnisse im Bereich der Alpen: Sauerstoffisotopenkurven kalkhaltiger Sedimente. *Geographica Helvetica*, 2: 99-104.
- Fairbanks, R. G., 1989. A 17 000 year glacio-eustatic sea level record: Influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature*, 342: 637-642.
- Gaillard, M.-J., 1984. A palaeohydrological study of Krageholmssjön (Scania, South Sweden). Regional vegetation, history and water-level changes. *Lundqua Report*, 25: 1-40.
- , 1985. Postglacial palaeoclimatic changes in Scandinavia and Central Europe. A tentative correlation based on studies of lake-level fluctuations. *Ecologia Mediterranea*, X 1: 159-175.
- Guiot, J. et Pons, A., 1986. Une méthode de reconstruction quantitative du climat à partir de chroniques pollénanalytiques: le climat de la France depuis 15000 ans. *Comptes rendus à l'Académie des Sciences, Paris*, 302-II: 911-916.
- Harrison, S.P., 1988. Reconstructing climate from lake level changes. *Lundqua Thesis*, 21.
- Harrison, S.P., Prentice, I.C. and Bartlein, P.J., 1992. Influence of insolation and glaciation on atmospheric circulation in the North Atlantic sector: Implication of GCM experiments for the late Quaternary climatology in Europe. *Quaternary Science Reviews*, 11: 283-299.
- Karpuz, N.K. and Jansen, E., 1992. A high-resolution diatom record of the last deglaciation from the SE Norwegian Sea: Documentation of rapid climatic changes. *Paleoceanography*, 7: 499-520.
- Kerschner, H., 1980. Outlines of the climate during the Egesen advance (Younger Dryas, 11000-10000 BP) in the central Alps of the western Tyrol, Austria. *Zeitschrift für Gletscherkunde und Glaziologie*, 16: 229-240.
- Lehman, S.J. and Keigwin, L.D., 1992. Sudden changes in North Atlantic circulation during the last deglaciation. *Nature*, 356: 757-762.

- Lotter, A.F., Reicher, U., Siegenthaler, U. and Birks, H.J.B., 1992. Late-glacial climatic oscillations as recorded in Swiss lake sediments. *Journal of Quaternary Science*, 7: 187-204.
- Magny, M., 1992a. Sédimentation et dynamique de comblement dans les lacs du Jura au cours des 15 derniers millénaires. *Revue d'Archéométrie*, 16: 27-49.
- 1992b. Holocene lake-level fluctuations in Jura and the northern subalpine ranges, France: Regional pattern and climatic implications. *Boreas*, 21: 319-334.
- 1994. Holocene climatic oscillations in Jura and Alps: Oceanic and solar forcing? *Comptes rendus à l'Académie des Sciences, Paris*, II-319: 667-674.
- 1995. Successive oceanic and solar forcing indicated by Younger Dryas and early Holocene climatic oscillations in the Jura. *Quaternary Research*, 43: 279-285.
- Magny, M. and Ruffaldi, P., 1994. A palaeohydrological record of Younger Dryas from lake Onoz in Jura, France. *Comptes rendus à l'Académie des Sciences, Paris*, II-319: 459-466.
- 1995. Younger Dryas and early Holocene lake-level fluctuations in Jura, France. *Boreas*, 24: 155-172.
- Markgraf, V., 1969. Moorkundliche und vegetationsgeschichtliche Untersuchungen an einem Moorsee an der Waldgrenze im Wallis. *Botanische Jahrbuch*, 89: 1-63.
- Mörner, N.-A., 1993. Global change: The high amplitude changes 13-10 ka ago — novel aspects. *Global and Planetary Change*, 7: 243-250.
- NASP Members, 1994. Climatic changes in areas adjacent to the North Atlantic during the last glacial-interglacial transition (14-9 ka BP): A contribution to IGCP-253. *Journal of Quaternary Science*, 9: 185-198.
- Patzelt, G., 1977. Der zeitliche Ablauf und das Ausmass postglazialer Klimaschwankungen in den Alpen, p. 248-259. In B. Frenzel, ed., *Dendrochronologie und postglaziale Klimaschwankungen in Europa*. Wiesbaden.
- Pons, A., de Beaulieu, J.L., Guiot, J. and Reille, M., 1987. The Younger Dryas in Southwestern Europe: An abrupt climatic change as evidenced from pollen records, p. 195-208. In W.H. Berger and L.D. Labeyrie, eds, *Abrupt climatic change*. Reidel Publ. Comp.
- Richard, H., 1983. Nouvelles contributions à l'histoire de la végétation franc-comtoise tardiglaciaire et holocène à partir des données de la palynologie. Thesis, Université de Franche-Comté, Besançon, 155 p.
- 1991. Analyses polliniques du Bugey : le Préboréal du lac de Bart, p. 31-34. In R. Vivian, ed., *Paléoenvironnement holocène et archéologie dans les Alpes du Nord et leur Piémont*. Comité des Travaux historiques et scientifiques, Paris.
- Ruddiman, W.F. and McIntyre, A., 1981. The North Atlantic Ocean during the last deglaciation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 35: 145-214.
- Ruffaldi, P., 1993. Histoire de la végétation du Jura méridional depuis le retrait du glacier würmien à partir des analyses palynologiques du lac de Cerin (Ain, France). Thesis, Université de Franche-Comté, Besançon, 254 p.
- Starkel, L., 1991. Long-distance correlation of fluvial events in the temperate zone, p. 473-495. In L. Starkel, K. J. Gregory and J. B. Thornes, eds., *Temperate palaeohydrology*. Wiley and Sons.
- Stuiver, M., Long, A. and R. Kra, R., 1993. Calibration 1993. *Radiocarbon*, 35.
- Stuiver, M. and Braziunas, T.F., 1993. Sun, ocean, climate and atmospheric $^{14}\text{CO}_2$: An evaluation of causal and spectral relationships. *The Holocene*, 3: 289-305.
- Stuiver M. and Reimer, P., 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon*, 35: 215-230.
- Walker, M.J.C., Griffiths, H.I., Ringwood, V. and Evans, J.G., 1993. An early-Holocene pollen, mollusc and ostracod sequence from lake marl at Llangorse Lake, South Wales, UK. *The Holocene*, 3: 138-149.
- Wegmüller, S., 1966. Ueber die spät- und postglaziale Vegetationsgeschichte des Südwestlichen Jura. *Beiträge zur geobotanischen Landesaufnahme der Schweiz*, 48: 1-144.
- Zbinden, H., Andree, M., Oeschger, A., Ammann, B., Lotter, A., Bonani, G. and Wöflü, W., 1989. Atmospheric radiocarbon at the end of the last glacial: An estimate based on AMS radiocarbon dates on terrestrial macrofossils from lake sediments. *Radiocarbon*, 31: 795-804.
- Zoller, H., 1977. Alter und Ausmass postglazialer Klimaschwankungen in den Schweizer Alpen, p. 271-281. In B. Frenzel, ed., *Dendrochronologie und Klimaschwankungen in Europa*. Steiner Verlag, Wiesbaden.